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Comparative analysis of order allocation methods and intelligent systems for effective download of production capacities of manufacturing enterprise

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Comparative analysis of order allocation methods and intelligent systems for effective download of production capacities of manufacturing enterprise

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Abstract. The article compares the planning systems of the enterprise, determines their opportunities to use simulation for the process of distribution of production orders. A comparative review of the methods used in production planning systems and the multi-agent approach in solving the problem of the allocation of production orders is carried out. The possibility of approaches in cases when it is impossible to perform production tasks within the established time frame is considered, as well as to effectively load the available capacities of the units. In case it is not possible to produce the necessary quantity to distribute the part to another, similar to the type of equipment used, but different from it by the quantity and production capacity of the unit. Transmission must be carried out under the condition of sufficient capacity in the subdivision. The results of theoretical and experimental studies are presented. In the process of work, we used the BPsim.MAS dynamic modeling system. An automated system with the possibility of using simulation for the allocation of production orders is considered.

1. Introduction
Execution of production orders on time is a priority for any enterprise, since the failure to meet deadlines can lead to loss of orders received, a decrease in reputation and, as a consequence, a decrease in sales. To fulfill orders in time, it is necessary to organize the activities inside the enterprise correctly and supply the necessary materials from suppliers. Organization of work within the enterprise implies rational organization of work between structural divisions in terms of rhythmic operation of excluding failures, delays and production of defective products. The alignment of the rhythmic work of the shops of the enterprise is possible if there is a production plan of the release date included in it and the required number of products for each unit. When delays and failures occur in one of the structural units, the consequences are reflected in the whole technological chain, which can affect the production time and cost of the products produced. To avoid delays, it is necessary to correctly distribute the range of products at the existing production facilities.
Factors that cause failures and delays may be due to the unexpected release of process equipment, the lack of personnel, the lack of materials and tools. Accounting for all production factors in the production schedule is not only difficult to compute, but also difficult to implement. In the case of production planning, taking into account the production capacities of the units, a situation may arise that a unit will not be able to produce the right quantity of products within the time limits due to a lack of resources, as a result of which the delivery time will be shifted or shattered. To solve this problem, it is necessary to consider the possibility of changing the technological route for manufacturing a group of parts, i.e. pick up a suitable workshop, which has a smaller load, the necessary equipment and the appropriate personnel. The replacement of the interchamber route is necessary to unload the capacity of the overloaded unit. When a new order appears at the enterprise, it is necessary to

recalculate the production plan and, in the event of an overload of a certain subdivision, adjust the technological route. If it is not possible to change the technological route of a group of parts, then consider changing the operating mode of the unit or shifting plans for the execution of existing orders. Analysis of the production capacities of units involved in the manufacture of products and the redistribution of the load between them is an important aspect that must be taken into account in the allocation of production orders of the enterprise. The distribution of production orders at the enterprise is occupied by so-called corporate information systems, which accumulate information about the loading of equipment, the number of orders, the terms of manufacture, the required product range.

2. Corporate Production Systems

Consider several similar systems.

2.1 Omega Production Information System

Information system Omega Production is the development of the Belarusian company Omega Software. This system is designed to manage the production and resources of the enterprise. The system is positioned as a corporate information system, and includes the automation of all business processes of the enterprise, being a kind of CALS-system. Omega Production is suitable for automation of industrial enterprises with the type of output - from single and small-scale to large-scale production.

2.2 SAP / R3 Information System

The Sap / R3 system is a corporate information system developed by the German company SAP Corporation. This system is widely used in various fields of activity, for example, banking, trade, industrial, etc. The use of several modules in industrial enterprises, such as Sap PLM, Sap ERP, Sap CRM, form a CALS-system. The main product of the company is the Sap ERP system of enterprise resource planning. To manage engineering data, the system does not have a complete set of functions, only specifications, material consumption rates and description of operations for manufactured products are present. Production planning is based on the MRP II planning methodology. In the absence of accurate data in the system, the production plan will contain incorrect data.

2.3 Information system "Frigate Corporation"

"Frigate Corporation" ERP-system is designed for medium and large enterprises and it is the development of the Russian company Information and Technology Center FRIGATE. The system is positioned as a corporate information system and is built on a modular platform. The module "Production" contains information on the management of engineering data at the level of the entry of technological maps, technological operations. When planning production, the MRP II planning methodology is used. To obtain the correct plans, you need to have accurate information in the system.

2.4 ERP Information System - Galaxy

Corporate information system ERP-Galaxy is one of the best systems presented by Russian developers. The architecture of the system can be represented as a two-level or a three-level system. ERP-Galaxy is a modular system. Each module is designed to automate individual, narrow tasks. A flexible modular system opens the possibility of constructing and using any configuration that meets the specific needs of the enterprise. A functional feature of this software product is the use of the MRP II standard to compile production plans of the enterprise. For production planning, the system must contain complete information about the products to be collected technological data, inventories and other production information with an accuracy of at least 95% to obtain the correct plans.

2.5 Microsoft Dynamics AX Information System

The Microsoft Dynamics AX Information System is software for enterprise resource planning, as well as tools for managing the entire enterprise, from the supply chain, procurement and personnel management to finance and joint projects. System Microsoft Dynamics AX has an integrated development environment Morph X in which there is a built-in development language X ++. Based on this development environment, it is possible to develop the required application model, for example, to create a form for displaying certain data. Management and production planning is based on the methodology of MRP II, as well as on the basis of APS methodology. The system is closely interconnected with the modules of "financial management" and "supply chain management", which allows you to get a full-featured solution for production management. The plan can be drawn up both "forward" and "back" taking into account the limited production capacity. Information for obtaining production plans must be accurate, and the completeness of the data should be at least 95%.

2.6 Smart Factory Information System

Smart Solutions' production planning system is one of the latest domestic developments. This system is positioned as a MES level system. The main difference from existing systems is the use of the multi agent approach as a production planning method [3]. This system is based on the device of networks of needs and opportunities, developed by VA. Wittich, P.O. Skobelevy and G.A. Rzhevsky. The main idea of the approach is to use software agents for each process or operations, as well as for each worker or equipment of the enterprise or workshop. Agents negotiate among themselves agree and find the best solutions for the speedy completion of their assigned task. Based on this approach, there is flexibility in comparison with other production systems due to the lack of need to recalculate the entire production plan when adding a new order. The functionality of these systems is presented in the table responsible for the management of production.

Table 1. Functions of production management in various IS.

№	Parameters	Omega Production	SAP/R3	Frigate Corporation	ERP – Galaxy	Microsoft Dynamics AX	Smart Factory
1	Dispatching production	+	+	+	+	+	+
2	Production planning	+	+	+	+	+	+
3	Inventory control	+	+	+	+	+	+
4	Production Management	+	+	+	+	+	+
5	Engineering data management	+	-	-	-	-	-
6	Simulation of the distribution of orders	-	-	-	-	-	-

These corporate information systems have similar functionality for solving common problems, for example, sales accounting, supply accounting, but there are also differences, for example, orientation on business analysis, accounting block, design and technological preparation of production. At the core of the production planning function are various methodologies, mathematical methods that calculate the distribution of orders for the same type of structural units. At the same time, none of the systems contains an imaging simulation module that can be an alternative to mathematical methods and methodologies for the process of planning production and distribution of parts to the same structural units. Playing the simulation model allows you to take into account the various production factors that may either not be taken into account in the calculations or increase the preparation time of the effective plan.

3. Formulation of the problem

Let's consider the task on an example of metallurgical shops entering into the machine-building enterprise with a full cycle of manufacturing. In the work on the production of metallurgical products, 4 metallurgical shops and 1 assembly shop, namely the Martenovsky workshop, Foundry shop No. 1 and No. 2, as well as the Machining shop and the Assembly shop, participate. Foundry shop # 2 is an auxiliary alternative route and is used when route 1 Foundry shop # 1 + The processing shop do not cope with the performance of production tasks. The range of shops consists of three different parts: part 1, 2 and 3, which enter the assembly shop and are assembled into a unit. Details have different end-to-end technological processes. Analysis of the statistical data of work in the shops showed that each type of part can have different types of marring at certain production stages and with different probability. An algorithm for sorting defective products, used by technologists, is known. The task is to produce three types of parts for a calendar month with the search for bottlenecks and the possibility of changing the technological route in case of exceeding the loading unit. We consider the solution of this problem with the help of classical solution methods.

4. Methods for solving the problem

This task resembles an ordinary queuing system, where each workshop is a separate QS.

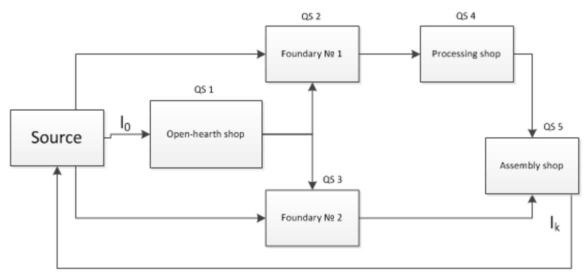

Figure 1. Structural diagram of the SMO network for the manufacture of parts and components

The considered network is an open stochastic network, which implies the dependence of the current process on the previous one. In the presented network technological processes of manufacturing of all details described in the considered task are united. The mechanism for the retraining of parts implies the separation after QS 1 on QS 2 + QS 4 and QS 3 in which different numbers of personnel and instruments are used. When the model is built in the SMO, the probability (P) of the transition of the system from the state S_n to the state S_{n+1} is used. The transition will be considered a technological operation and a change in the state of the part from operation to operation. The technological cycle for manufacturing a part is presented in the form of a matrix of transition probabilities.

Table 2. Matrix probability of transitions of detail

	S0	S1	S2	S3	S4	S5	S6	S7	S8
S0	0	1	0	0	0	0	0	0	0
S1	0	0	0,5	0,5	0	0	0	0	0
S2	0	0	0	0	1	0	0	0	0
S3	0	0	0	0	1	0	0	0	0

S4	0,15	0	0	0	0	0,57	0,28	0	0
S5	0	0	0	0	0	0	0	0,33	0,67
S6	0	0	0	0	0	1	0	0	0
S7	0	0	0	0	0	0	0	0	1
S8	P	0	0	0	0	0	0	0	0

In this model, the number of tasks received is equal to the number of completed tasks, that is, the intensity of the withdrawal of applications from the system $\lambda_k = \lambda_0$ is equal to the intensity of their receipt. When executing applications, a marriage occurs in the production of parts, according to the task at hand, in the event of which a supplementary application (task) is generated to cover the deficit that has arisen on the completed application. This application does not come from the source (λ_0), but from the QS 1.

Solving this task with the application of the classical approach, we can conclude that the application of a change in the technological route in the production of the item-assembly units is not possible due to the setting of parameters in the probability matrix with the distribution of flows. Change and transfer order in the case of the release of production capacity without recalculation is not possible. The application of this approach is effective in determining the "narrow" production sites.

Another classical approach is linear programming, namely the widely known simplex method. This method is used to find the extremum of linear functions of several variables under linear constraints imposed on variables. The problem under consideration has a number of limitations, an extremum and several variables. To solve the problem under consideration, we define the constraints for the compilation of equations.

Table 3. Limitations of the tasks

Parameters	Node		Value
	R.1	R.2	
Number of defective parts by parts (average value)	5,32	4,85	≤ 600
The total laboriousness of those. process by 1 unit. (n / h) (total for the shops, taking into account the number of equipment)	8,03	23,1 9	≤ 995
Profit from 1 ed. manufactured products	9	10	Max
Volume of output	x_1	x_2	

Making profit in the distribution of orders is the main task when solving the system by the simplex method. Restrictions on the equation are obtained on the basis of the maximum possible marriage by parts and the fund of working hours of structural units, minus breaks.
The solution of the system of equations, which was obtained from the data of the table, led to a specific decision on the allocation of orders and the maximization of the function in question, but this is also impossible to define "narrow" production spaces in contrast to the QS approach, and also with the increase in various restrictions, the dimension of the problem , which will inevitably lead to an increase in the time required to obtain the necessary solution.
An alternative to QS and Simplex method can be the model of multi-agent resource conversion process (MPPP) [1-2]. In the process of development, the model of workshops is expanded by an intelligent agent (IA) [8-13], which, based on data on the production capacity of the same units, makes a decision on the distribution of orders among structural divisions, or their division if necessary. The basis of the IA is the capability analysis algorithm, which is: production capacity for each unit. This indicator shows how much the shop is currently loaded. IA receives information about the loading of units (in our case there are two). When the production order is received, the agent calculates the cost of completing the order in each structural unit in accordance with the established terms, the availability of technological equipment, personnel, tools that participate in the production process is taken into account. If according to the criteria obtained the most beneficial route is No. 1 (Foundry shop No. 1 + Machining shop), then the order "leaves" in this direction, if not then on route No. 2 (Foundry shop No. 2). In the event that none of the units can fully execute the production order, then the order is divided and distributed to the shops. The upper level of the decomposition of the model of the MAPP in the environment BPsim.MAS.

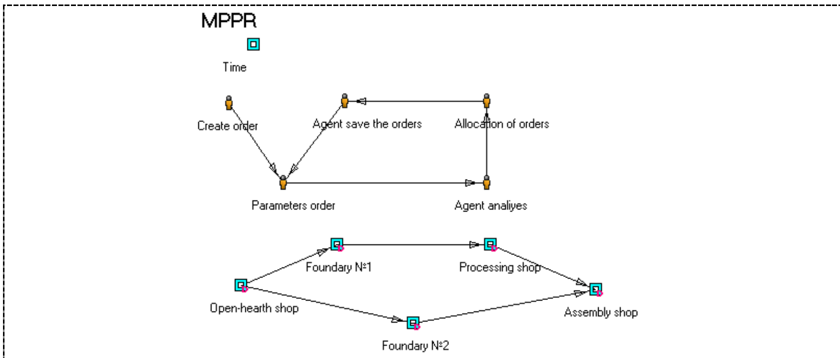

Figure 2. The upper level of the decomposition of the MPPR model

The result of the model playing was the distribution of orders along technological routes according to the maximization of profit for the enterprise. The data obtained during the experiments coincide with the data obtained in the simplex method. The application of the multi-agent approach in solving similar problems with large dimensions gives an effective solution on the basis of an analysis of many limiting factors that are more difficult to take into account when applying classical mathematical approaches.

5. Experimental results

To identify the strengths and weaknesses of each method, criteria were drawn reflecting the specifics of the subject area.

Table 4. Comparison of approaches

Criteria / methods	QS	Simplex method	Simulation modeling
Use of funds (process equipment)	-	+	+
Production plan, manufacturing time	-	-	+
Resource flows (1 route, 2 routes)	-/+	-/+	+/+
Planning with constraints (time / resources / tools)	-/+/-	-/+/+	+/+/+
Analysis of "narrow" production sites	+	-	+
Dispatching production	-	-	+

The criteria presented in the table refer to a stochastic system in which changes associated with production activity occur over time. Accounting for dynamically changing parameters is an important element in solving such problems.
The use of simulation modeling to solve the problems of planning and distribution of production orders for the same type of structural is more effective in comparison with traditional mathematical methods. Consider the system and the interaction of its modules, where the proposed solution is implemented programmatically.

6. Program implementation in automated system AS RMP

AS RMP is a web-based system designed for tracking, controlling, modeling, analyzing and improving processes release of metallurgical products.

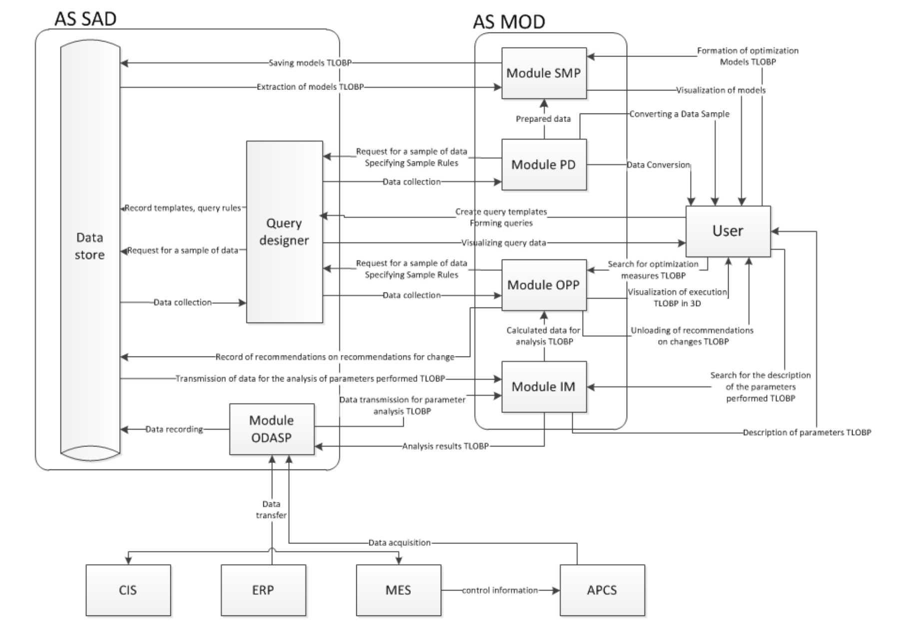

Figure 3. System Infrastructure and Module Interaction

Simulation modeling in the AS of the RMP directly provides the modules of the SMP (models developer), OPP (Enterprise Process Optimization), IM (models integration). Consider these modules.

6.1 Module SMP

The SMP module serves to build models of processes (technological, logistics, organizational (business) processes (TLOBP) and their modifications. The simulation model is based on the multi-agent model of the resource conversion process [3], which is used to study technological, logistical, organizational (business) processes, organizational and technical systems and offers integration of the following methods: simulation, expert, situational and multi-agent modeling.

The main functions of the SMP module include the following:

1) creation, modification and recording in HD (data store [14-15]) models of TLOBP with the help of a visual designer of models of multi-agent simulation processes, trees for analyzing process parameters, based on the web interface;

2) process-independent execution of the process model as a separate computational process;

3) the launch and simultaneous execution of several instances of the process models created by the SMP module;

4) coordination of input and output parameters of the process model created with the help of the SMP module, with the parameters of real technological processes for the implementation of the model in the IM module.

6.2 Enterprise Process Optimization Module

The main functions of the OPP module are as follows:

1) obtaining settlement data from the module MI;

2) obtaining a sample of data from the fault module;

3) obtaining the results of the data preparation settings created in the PD module [14-15];

4) obtaining the values of the parameters of the executed TLOBP when interacting with the module ODASP;

5) optimization of TLOBP based on the methods of simulation, multi agent, expert, situational modeling [3], a method for analyzing and eliminating the bottlenecks of TLOBP [4]: using the mechanism for planning and conducting experiments on the simulation model of the enterprise process; on the basis of a hybrid evolutionary-simulation algorithm [5];

6.3 Data exchange module with automated enterprise systems (ODASP)

Functionally, the module ODASP [7] corresponds to the class of the corporate data bus (Enterprise Services Bus). ODASP can collect data from heterogeneous external information systems and in turn serve as a source of information for them. This feature is implemented using a bidirectional asynchronous event mechanism [7]. The main functions of the ODASP module include the following:

1) obtaining data from the AC TP;
2) obtaining data from CIS, MES, ERP-systems;
3) data output in CIS, MES, ERP-system;
4) write data to the CD.

6.4 Module integration models

Module integration models [6] interacts with modules ODASP, QD, PD in real time. The interaction of the module MI with the module ODASP allows to solve the tasks of control, planning, reassignment and monitoring of the execution of processes, the operation of the units and the parameters of the units of production (EP). Thus, we can talk about the AS of the RMP as an open simulation system. The main functions of the MI module include the following:

1) obtaining data from the modules ODASP, QD, PD;
2) obtaining a description of the TLOBP from the HD module;
3) analysis of the parameters performed by the TLOBP (duration - not more than 30 minutes).
4) issuing the results of the analysis to the module ODASP; Tests of the AS RMP were carried out in solving problems for converter and rolling production of a metallurgical enterprise.

7. Conclusion

The results obtained in the course of calculations and experiments indicate the priority of using simulation modeling. The application of this approach is justified in the case of large-dimensional problems, where it is necessary to take into account not only dynamically changing parameters, but also a number of limitations present in the system. The implementation of this approach is considered using the example of the AS RMP, where a hybrid approach is used to integrate multi-agent simulation, a method for analyzing and eliminating process bottlenecks, and evolutionary modeling.

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